Magnetic Flux Cancellation as the Trigger Mechanism of Solar Coronal Jets

Riley A. McGlasson[1], Navdeep K. Panesar[2], Alphonse C. Sterling[2], Ronald L. Moore[2,3]

[1]Macalester College, Saint Paul, MN, [2]NASA Marshall Space Flight Center, Huntsville, AL ,

[3]Center for Space Plasma and Aeronomic Research (CSPAR), UAH, Huntsville, AL

Abstract

Coronal jets are narrow eruptions in the solar corona, and are often observed in extreme ultraviolet (EUV) and X-Ray images. They occur everywhere on the solar disk: in active regions, quiet regions, and coronal holes (Raouafi et al. 2016). Recent studies indicate that most coronal jets in quiet regions and coronal holes are driven by the eruption of a minifilament (Sterling et al. 2015), and that this eruption follows flux cancellation at the magnetic neutral line under the pre-eruption minifilament (Panesar et al. 2016). We confirm this picture for a large sample of jets in quiet regions and coronal holes using multithermal extreme ultraviolet (EUV) images from the *Solar Dynamics Observatory (SDO)*/Atmospheric Imaging Assembly (AIA) and line-of-sight magnetograms from the *SDO*/Helioseismic and Magnetic Imager (HMI). We report observations of 60 randomly selected jet eruptions. We have analyzed the magnetic cause of these eruptions and measured the base size and the duration of each jet using routines in SolarSoft IDL. By examining the evolutionary changes in the magnetic field before, during, and after jet eruption, we found that each of these jets resulted from minifilament eruption triggered by flux cancellation at the neutral line. In agreement with the above studies, we found our jets to have an average base diameter of 7600 ± 2700 km and an average jet-growth duration of 9.0 ± 3.6 minutes. These observations confirm that minifilament eruption is the driver and that magnetic flux cancellation is the primary trigger mechanism for nearly all coronal hole and quiet region coronal jet eruptions.

Background

Solar coronal jets are narrow, short-lived eruptions that occur frequently throughout the entire solar disk (Raouafi et al. 2016): quiet regions, coronal holes, and on the edge of active regions. These eruptions are often observed in extreme ultraviolet (EUV) and X-ray emission (Raouafi et al. 2016). Previous EUV observations by Panesar et al. (2016) have observed an average base width of 17,000 ± 600 km and an average jet duration of 12 minutes. Recent studies indicate that most coronal jets in quiet regions (Panesar et al. 2016) and coronal holes are driven by the eruption of a minifilament (Sterling et al. 2015). Because Sterling et al. (2015) only looked at jets near the limb, they had no conclusive results regarding the magnetic origin of these minifilaments. The study by Panesar et al. (2016) followed this by investigating the magnetic origin of 10 coronal jets and observed a pattern of flux cancellation at the magnetic neutral line prior to the formation of a minifilament. Here we seek to confirm this observation of jet eruption triggering by flux cancellation with a larger sample of 60 jets.

Quiet Region Jet

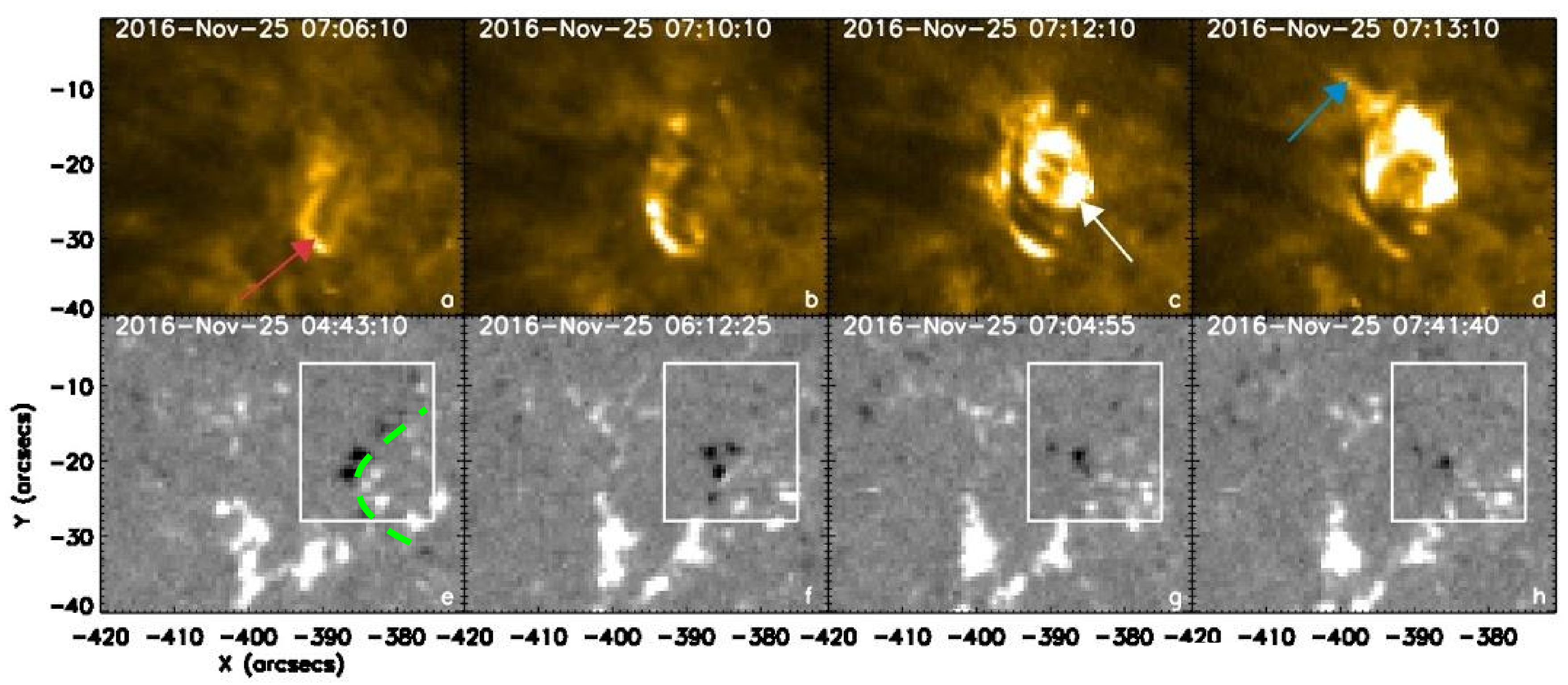

Figure 1: Quiet region jet observed on 2016 November 25- Panels (a)-(d) show 171 Å AIA intensity images. The red arrow in panel (a) points to the minifilament. The white arrow in panel (c) shows the jet bright point (JBP). The blue arrow in panel (d) indicates the jet spire next to the erupting filament. Panels (e)-(h) show HMI magnetogram images of the same region. The boxed areas in panels (e)-(h) enclose the measured flux plotted in figure 2. The green dashed line in panel (e) roughly outlines the magnetic neutral line.

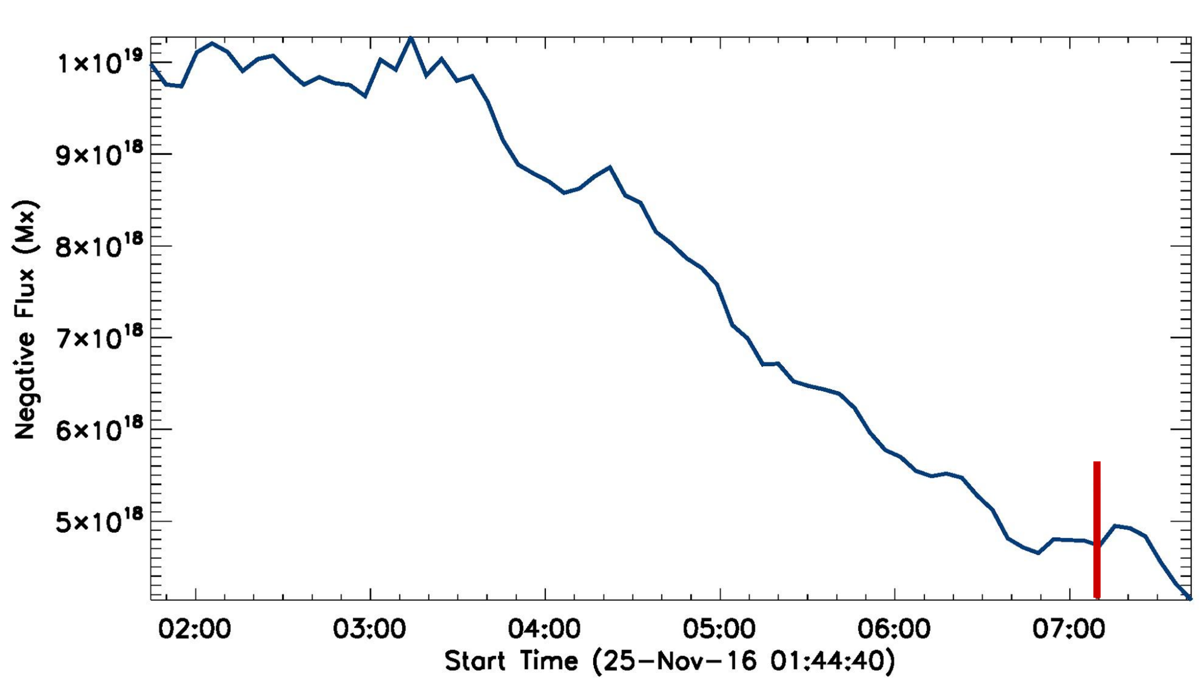

Figure 2: Flux cancellation plot for 2016 November 25- Plots the minority (negative) flux within the boxes in figure 1(e)-(h) as a function of time. The red line designates the time of jet onset (07:10 UT).

Instrumentation and Data

This study was carried out using multithermal (304 Å, 171 Å, 193 Å, and 211 Å) EUV images from *SDO*/AIA to study the evolution of the minifilament and jet spire. *SDO*/AIA produces high-resolution (0.6” pixel^{-1}) full-Sun images in seven EUV wavelengths (Lemen et al. 2012). We primarily used 171 Å and 193 Å images for this study. We found the cool minifilament material to be best seen in 171 Å (peak temperature: 600,000 K; Lemen et al. 2012). We use 193 Å (peak temperature: 1,500,000 K) and 211 Å (peak temperature: 2,000,000 K) images to look at jets in coronal holes. To analyze the magnetic field evolution, we used line-of-sight magnetograms from *SDO*/HMI (Scherrer et al. 2012). This instrument produces high-resolution (0.5” pixel^{-1}) line-of-sight magnetograms which allow us to closely examine the photospheric magnetic field around the jet-base region. We use magnetogram data to track the evolution of the photospheric magnetic flux in the jet-base region from approximately 5 hours prior to until 1 hour after jet eruption .

For this study we randomly selected 60 coronal jets in quiet regions and coronal holes using Jhelioviewer software (Mueller et al. 2017). We found 30 jets in quiet regions and 30 in coronal holes. We downloaded SDO/AIA and SDO/HMI for all 60 jets from the Joint Science Operations Center (JSOC): 2 hours of AIA data at a 1 minute cadence and 6 hours of HMI data at about a 5 minute cadence of a 200x150’’ area surrounding each jet . We then derotated all of the HMI and AIA images with respect to a particular time in order to account for solar rotation. With the derotated data, we selected a smaller field of view for each event that focused closely on the jet-base region to perform measurements on, and make movies of, each jet.

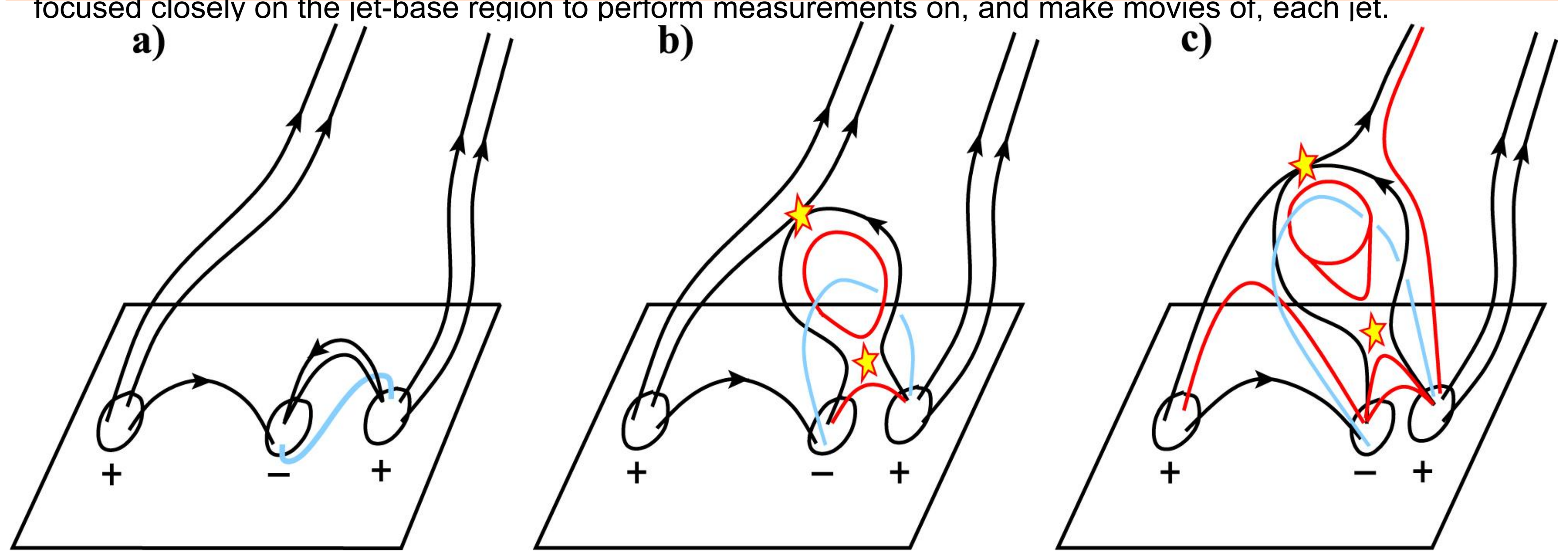

Figure 3: From Panesar et al. (2016), this diagram shows the evolution of a coronal jet eruption with the rectangular box representing the solar surface and the ellipses representing both the positive and the negative polarity magnetic flux patches. The blue line represents the minifilament which is enveloped by the magnetic field lines above, as can clearly be seen in panel (a). As the negative minority flux patch approaches and cancels with the positive majority flux patch on the right, the minifilament field begins to erupt outwards as in panel (b). This results in the internal reconnection between the minifilament-carrying field (lower star) as well as external reconnection with the adjacent field line (upper star). External reconnection produces new field lines represented by the red lines in panel (c), including the far-reaching red field line along which the jet escapes, forming the jet spire.

Results

We have examined the evolution of 60 on-disk quiet-region and coronal hole jets using EUV images from *SDO*/AIA to track the structure of the jets as well as using line-of-sight magnetograms from *SDO*/HMI to analyze the magnetic field evolution of the jet base region. In this poster we show two detailed examples of coronal jets in figure 1 (quiet region jet) and figure 4 (coronal hole jet). Both jets exhibit a clear minifilament at the neutral line (figure 1(a) and figure 4(a)) prior to onset. The white boxes in figure 1(e-h) and figure 4(e-h) show the area in which we quantitatively measured the minority magnetic flux through time. We were careful to be sure that none of the measured minority flux flowed across the boundary of the box. As seen in figures 2 and 5, which display this flux through time, we find a clear pattern of flux cancellation before and during the eruption in both the quiet region and coronal hole jets. We confirmed this observation with the rest of the 60 jet sample.

As the opposite polarity magnetic flux patches are cancelling at the neutral line (see figures 1(e-h) and 4(e-h)), the field enveloping the minifilament (minifilament field) destabilizes and begins to erupt (see figure 3(b)). This minifilament eruption takes place at the neutral line and results in internal reconnection within the minifilament field (represented by the lower star in figure 3(b,c)). This reconnection then produces the jet bright point (white arrow in figure 1(c) and figure 4(c)) at the neutral line. As the eruption continues, the minifilament field goes through external reconnection with the surrounding magnetic field (represented by the upper star in figure 3(b,c)), allowing the minifilament plasma to flow along that field line and become a part of the resulting jet spire (figure 3(c)).

We find that the triggering mechanism for all 60 jet eruptions is flux cancellation, here shown by the two jet examples in figures 1 and 3. This observation is consistent with the findings of Panesar et al. (2016), who observed flux cancellation in a sample of 10 quiet-region coronal jets. Additionally, we present measurements of base width and duration for all 60 jets. Jet base width was measured by taking the average of three distinct measurements across the jet base in 171 Å approximately 1 minute prior to jet spire eruption. By doing so, we found the average jet base to be 7600 ± 2700 km. Jet duration was measured in 171 Å from the intitial brightening of the jet base until the spire was at a maximum height. The jets in this sample had an average duration of 9.0 ± 3.6 minutes.

Coronal Hole Jet

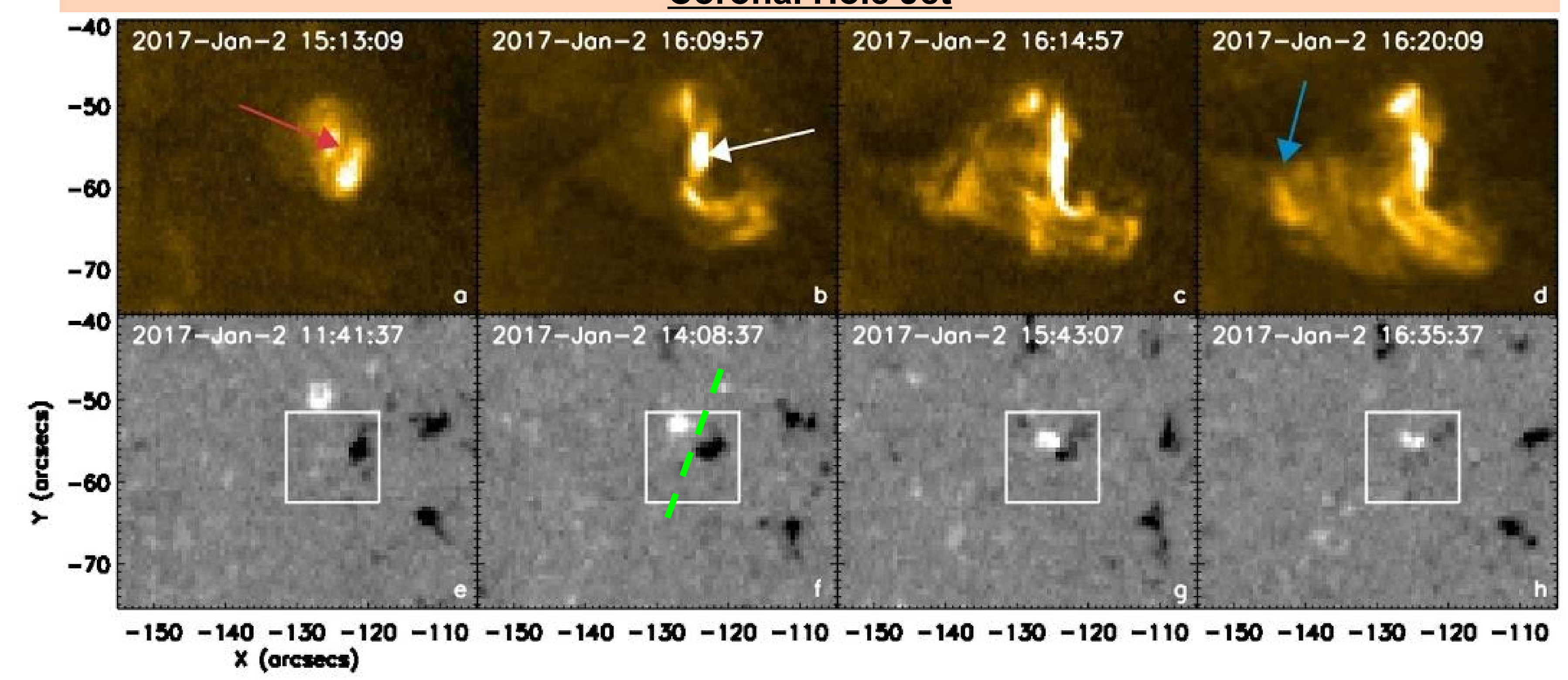

Figure 4: Evolution of a coronal hole jet observed on 2017 January 2- Panels (a)-(d) show 171 Å AIA intensity images. The red arrow in panel (a) points to the minifilament. The white arrow in panel (c) shows the jet bright point (JBP). The blue arrow in panel (d) indicates the jet spire next to the erupting filament. Panels (e)-(h) show HMI magnetogram images of the same region. The boxed areas in panels (e)-(h) enclose the measured flux plotted in figure 5. The green dashed line in panel (f) roughly outlines the magnetic neutral line where the minifilament resides prior to eruption.

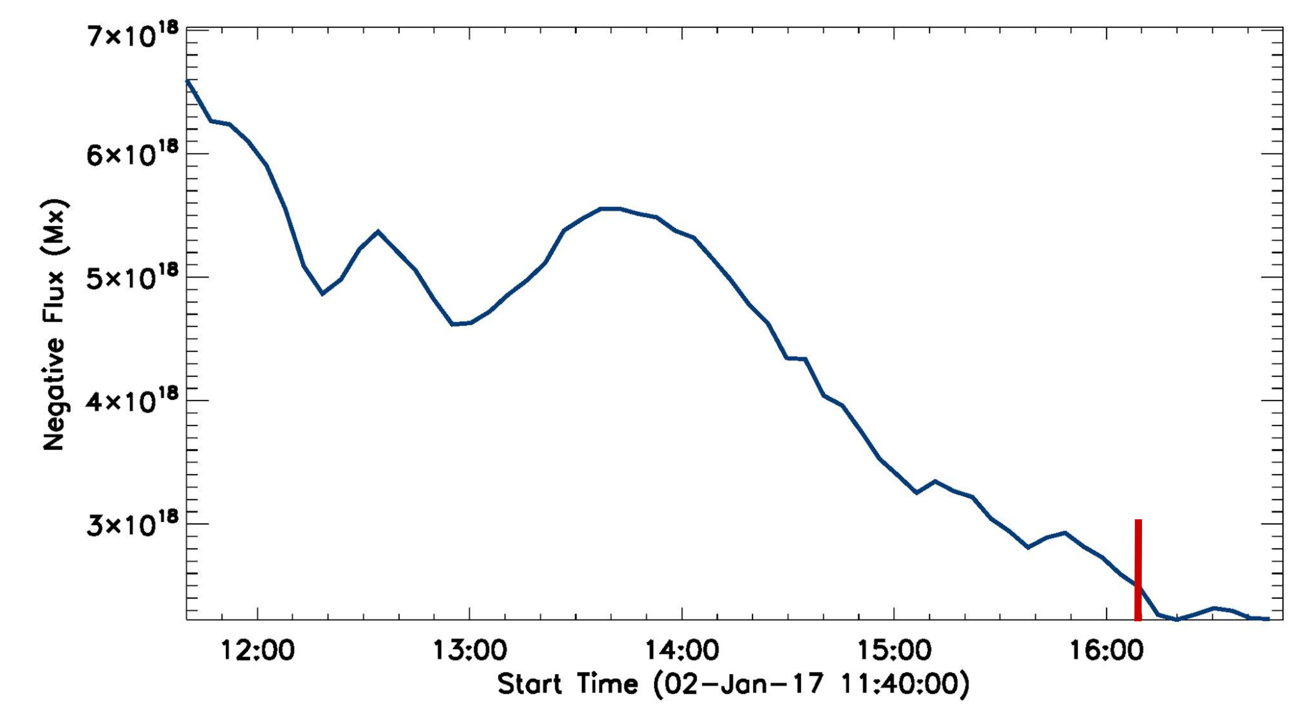

Figure 5: Flux cancellation plot of coronal hole jet observed on 2017 January 2. Plots the minority (negative) flux within the boxes in figure 4(e)-(h) as a function of time. The red line designates the time of jet onset (16:09 UT).

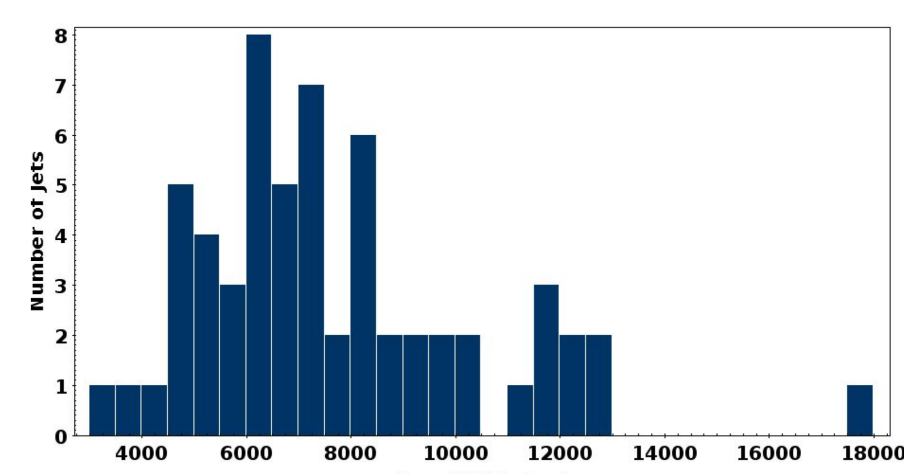

Figure 6: Histogram displaying the jet base width in kilometers of all 60 coronal jets. Average base width: 7600 +/- 2700 km

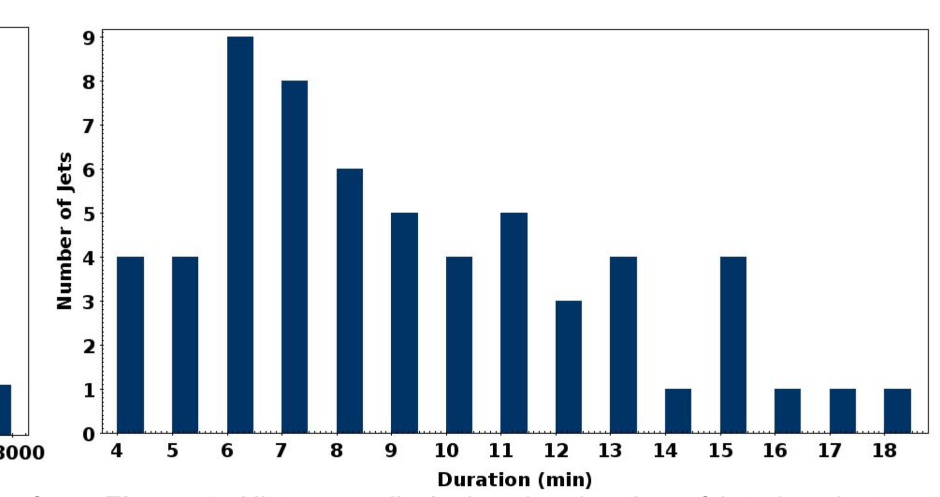

Figure 7: Histogram displaying the duration of jets in minutes from onset to maximum jet spire of all 60 coronal jets. Average duration: 9.0 +/- 3.6 min

Conclusion

We report the trigger mechanism of 60 randomly selected, on-disk solar coronal jets in quiet regions and coronal holes, as well as the duration and base width of each jet. From our observations of the magnetic flux behavior of coronal jets in quiet regions and coronal holes, we find that prior to each jet eruption, a minifilament is present at the neutral line. This minifilament erupts due to continuous flux cancellation at the neutral line. Additionally, we find an average base width of 7600 ± 2700 km for our jets. We also find the 60 jets to have an average duration of 9.0 ± 3.6 minutes.

Acknowledgements

Special thanks to Dr. Navdeep Panesar for her time and mentorship throughout the research process, NASA Marshall Spaceflight Center, the Center for Space Plasma and Aeronomic Research at the University of Alabama in Huntsville, and the National Science foundation for supporting this study. This Research Experience for Undergraduates program is funded by the National Science Foundation under grant No. AGS-1460767.

References

Lemen, J. R., Title, A. M., Akin, D. J., et al. 2012, SoPh, 275, 17
Panesar, N. K., Sterling, A. C., Moore, R. L., & Chakrapani, P. 2016, ApJL, 832, L7
Raouafi, N., Patsourakos, S., Pariat, E., et al. 2016, SSRv, *201*, 1
Scherrer, P., Schou, J., Bush, R., et al. 2011, SoPh, *275*, 207
Sterling, A. C., Moore, R. L., Falconer, D. & Adams, M. 2015, Nature, *523*, 437
Mueller, D.,Nicula, B., Felix, S., Verstringe, F., et al. 2017, A&A,doi:10.1051/0004-6361/201730893